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WHAT WAS LEARNED FROM OVER 20 YEARS OF EVALUATING BIOFUNGICIDES

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In 1994, when I started evaluating biofungicides for diseases of vegetable crops, there were very few products on the market. First products tested were Kaligreen and Armicarb (potassium bicarbonate), AQ-10 (biocontrol; discontinued) and Milsana (plant extract; today marketed as Regalia). There now are a large number and diversity of products, at least as many as conventional fungicides. The active ingredient in biopesticides are natural substances. I have information about biopesticides and crop lists of products with labeled diseases at <https://www.vegetables.cornell.edu/ipm/diseases/biopesticides/>. Most of my evaluations have been for cucurbit powdery mildew. I have also determined efficacy of biofungicides for cucurbit downy mildew, Phytophthora blight, basil downy mildew, and foliar diseases (Septoria leaf spot and powdery mildew) of tomato. I have lists of products I have tested with summary statements about their efficacy at <https://blogs.cornell.edu/livepath/research/organic-disease-management/>. Full reports are available to download there. Most evaluations have been biopesticides applied solely. More recent research has included programs with more than one biofungicide and programs with conventional fungicides, and biofungicides applied to resistant varieties. I also have photographs posted from recent evaluations.

In addition to my results, I have efficacy results from reports published by other researchers at <https://www.vegetables.cornell.edu/ipm/diseases/biopesticides/> in a downloadable excel file posted under 'More information'. Since it is an excel file, the contents can be sorted by crop, disease, product, and/or efficacy. I recommend focusing on efficacy calculated from the data which is in columns V – Y. To facilitate, use the hide command to hide at least columns J – U. A treatment is labeled as effective (assigned 'E' and highlighted green in columns W and Y) when the treatment disease rating is significantly different than the untreated control (the two treatments have different mean separation letters from statistical analysis). It is valuable to also look at calculated % control in columns V and X. Sometimes, while effective, the level of control is low (less than 10%) and sometimes, due to high variability in an experiment, a biofungicide is ineffective although control was greater than 50%.

Interest in biofungicides stems from their positive attributes, in particular their low toxicity and low potential for resistance to develop in target pathogens. Low toxicity means they typically have short re-entry interval (REI) and pre-harvest interval (PHI), offering growers flexibility in harvest operations. Most biopesticides have been granted an exemption from the requirement of a tolerance, aka maximum residue level (MRL), which is the legal limit for a pesticide chemical residue in or on a food. Combined with low potential for resistance development means there are no limitations on number of consecutive and total number of applications as there are for most conventional fungicides. While toxicity typically is low, before using any biopesticide, check the precautionary statements on its label to find out what personal protective equipment (PPE) is required for those handling the product and whether it has potential to affect birds, pollinators and other beneficial insects, and mammals.

What I have concluded about biofungicides from my experience evaluating them and from results of research conducted by others includes:

1. Biofungicides for foliar and fruit diseases have contact activity. Therefore, it is best to use a preventive (proactive) application schedule, second best is to start when symptoms first seen, and also to strive for thorough coverage especially of the lower surface of leaves. Also reapply on a regular (e.g. weekly) schedule and after rain. There are claims of disease resistance being activated in treated plants for some biofungicides, in particular those with a *Bacillus* species as the active ingredient. Two metabolic pathways involved in resistance are the salicylic acid pathway which results in systemic acquired resistance (SAR) and the jasmonic acid pathway which results in induced systemic resistance (ISR). Model plant systems such as *Arabidopsis* have been used to document activation of one of these pathways following application of a biofungicide. There is need for research examining resistance activation in a diversity of crop plants to a diversity of pathogens under field conditions. From my experience testing biofungicides for cucurbit powdery mildew mostly in pumpkins, it does not appear that resistance is being activated or it is not effective for this disease based on the fact I have documented control on the upper surface of leaves with a diversity of biofungicides, but not on the lower leaf surface where it is difficult to directly deliver spray material due to leaf size and canopy architecture.

2. Biofungicides, like most conventional fungicides, do not have the ability to cure infections. Start applications before infection for maximum efficacy.

3. Biofungicides generally are good components of an organic management program, providing a useful alternative to at least some copper fungicide applications. Phosphorous acids (phosphonates) are among the very few biofungicides not approved for use in organic production.

4. Applying different biofungicides together or in alternation might be the most efficacious approach to managing diseases.

5. Biofungicides have good potential for managing bacterial and root diseases in conventionally as well as organically-grown crops because there is a lack of effective alternative products.

6. Biofungicides generally are not as effective as modern, targeted conventional fungicides.

7. Best approaches to incorporating biofungicides into a conventional fungicide program to reduce use of conventional fungicides are to apply biofungicides in place of contact (protectant) fungicides (ex. chlorothalonil) in the program and in place of targeted conventional fungicides for the last applications to a crop.

Recommendations to maximize success using biopesticides to manage plant diseases:

1. Check efficacy data when selecting products to know what to expect. Look for data from field evaluations; products generally perform better under controlled laboratory and greenhouse conditions than outdoors. Note that efficacy is not considered by US EPA when making registration decisions.

2. Make sure target diseases have been correctly identified. I have tips on diagnosis at <https://www.vegetables.cornell.edu/pest-management/disease-factsheets/general-tips-on-identifying-plant-diseases/>.

3. Check expiration date before purchasing a biopesticide, especially those that have a microbe as the active ingredient, to ensure it is still good and the contents can be used up before that date. Follow label storage recommendations to ensure product maintains activity.

4. Use biofungicides as a component of an integrated management program with cultural practices such as rotation, pathogen-free seed, resistant varieties, sanitation, weed control, etc. Also check crops each week for disease symptoms as well as insect pests. Keep dated notes about what seen and take photographs.

5. Use preventive application schedule based on disease occurrence in crops during previous years.

6. Apply biofungicides in a way that maximizes spray coverage on all leaf surfaces. Drop nozzles can be very effective, especially with crops like tomato and pepper. Nozzles can also affect coverage. Use water sensitive paper to assess coverage. Apply such that there is no runoff because amount of spray deposit is more just before runoff than afterwards.

7. Use a regular (weekly) schedule with applications adjusted based on weather and conditions. Apply before rain rather than after because most fungal and bacterial pathogen infect when plant tissue is wet. Re-apply after an intense rain with about 2 inches of rainfall because this will remove a lot of residue. Applying more frequently than once a week may also be warranted when conditions are very favorable for the target disease.

8. Determine best use patterns for biofungicides by reading the label, checking company website, and asking company technical staff. For example, an adjuvant may be recommended, in particular a spreader/sticker. Spray solution pH can affect product performance: pH between 6 and 8 is best for most microbial-based biofungicides. There may be conditions (e.g. temperature, time of day) that are best for making an applications or to be avoided. Also check about compatibility of potential tank mixtures. Copper fungicides can be a good partner including with many microbial-based biofungicides, but not all. The container for liquid formulations should be shaken well right before use because settling can occur.

9. Knowing the mode of action of biofungicides (how they work) can be useful.

10. Assess control obtained. I suggest taking photographs and jotting down a description of disease severity observed 7-10 days after the last application. Also note how favorable conditions were for the disease. Unfavorable conditions (ex. few rain events) can be the main reason for limited disease development.



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